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CRACKS, A FORTRAN IV DIGITAL COMPUTER PROGRAM FOR CRACK PROPAGATION ANALYSIS

ROBERT M. ENGLE, JR.

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FOREWORD

This report was prepared by Robert M. Engle, Jr. of the Solid Mechanics Branch, Structures Division, Air Force Flight Dynamics Laboratory. The work was conducted in-house under Project 1467, "Structural Analysis Methods," Task 146704, "Structural Fatigue Analysis," with Mr. Robert M. Bader as Project Engineer.

This report covers research conducted from July 1969 through February 1970.

This technical report has been reviewed and is approved.

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ABSTRACT

This report presents a detailed description of a computer program for analyzing crack propagation in cyclic loaded structures. The program has the option of using relationships derived by Forman or by Paris for crack growth. Provisions are made for both surface flaws and "through cracks" as well as the transition from the former to the latter. The program utilizes a block loading concept wherein the load is applied for a given number of cycles rather than applied from one cycle number to another cycle number. Additional features of the program are: variable print interval, variable integration interval, and optional formats for loads input. Detailed input instructions and an illustrative problem are presented.

TABLE OF CONTENTS

SYMBOLS

Mathematical Symbol	FORTRAN Symbol	Physical Definition
a	A	Half crack length
a_o	AZERO	Initial half crack length
b	B(2)	Plate half-width
C	C	Material constant
c	SMALLC	Surface flaw half-width
da/dN	DADN	Crack propagation rate
K_c	KSUBC	Critical stress intensity factor
ℓ_c	B(3)	Characteristic length
N	N	Cycle
n	SMALLN	Material constant
R	R	Stress ratio ($\sigma_{max}/\sigma_{min}$)
t	THICK	Material thickness
β_I	BETA(I)	Individual correction factor
β_T	BETAT	Total combined correction factor
ΔK	DELTAK	Stress intensity factor range
$\Delta\sigma$	TSUBA	Applied tensile stress range (σ_{max} - σ_{min})
σ	SIGMA	Applied tensile stress
σ_{ys}	SIGMAY	Material yield stress

SECTION I

INTRODUCTION

The total service life of a structure is often dependent upon the total amount of crack growth which can be tolerated prior to the formation of the critical size flaw or crack. An analysis which can predict this growth, under variable amplitude loading, leading to the critical crack length is a valuable aid in establishing safe operating periods and inspection intervals.

An automated procedure is presented in this report which will permit the user to examine the crack propagation of various flaw shapes including surface flaws. Provision is also made for transition from a surface flaw to a "through crack." The computer program, CRACKS, is written entirely in FORTRAN IV for the IBM 7044/7094 Direct Coupled System (DCS). A source listing is given in Appendix I.

SECTION II

MATHEMATICAL FORMULATION

1. CRACK PROPAGATION RATE

In the early 1960's, P. C. Paris (Reference 1) determined that the rate of crack propagation under cyclic loading is primarily related to the stress-intensity-factor range, ΔK. Paris proposed an exponential relationship of the following form:

$$\frac{da}{dN} = C_p \, (\Delta K)^{n_p} \tag{1}$$

In 1967, Forman, Kearney, and Engle published a paper (Reference 2), in which Paris' equation was modified to take into account the effects of load ratio, R, and crack growth instability as ΔK approaches K_c. These modifications led to a relationship of the following form:

$$\frac{da}{dN} = \frac{C_F \, (\Delta K)^{n_F}}{(1-R)\, K_c - \Delta K} \tag{2}$$

Both of these relationships have proved useful in crack-propagation analysis and hence provision is made in CRACKS for both.

2. STRESS INTENSITY FACTOR

The basic unit of fracture mechanics is the stress intensity factor, K. For crack propagation analysis, the applied crack tip stress intensity factor, K, must be less than the material's toughness (K_c) or fracture occurs. This applied crack tip stress intensity factor, K, is a function of geometry and type of loading. For a central crack in an infinite width plate, the stress intensity factor may be written as follows:

$$K = \sigma \sqrt{\pi a} \tag{3}$$

This equation will take different forms based upon the geometry and the loading. For many cases, however, these effects may be treated as modifiers or correction factors to Equation 3. Thus, a more general form would be:

$$K = \sigma \sqrt{\pi a} \; \beta_T \tag{4}$$

These correction factors will be described in more detail in the following section.

Some investigators (Reference 3) have modified Equation 4 by removing the factor π from under the radical giving:

$$K = \sigma \sqrt{a}\ \beta_T \tag{5}$$

Equation 4 and Equation 5 are both prevalent in the literature and are included in the computer program.

The stress-intensity-factor range, ΔK, is defined as:

$$\Delta K = K_{max} - K_{min}$$

Substituting Equation 4 into this relation gives:

$$\Delta K = \Delta\sigma \sqrt{\pi a}\ \beta_T \tag{6}$$

Similarly, substituting Equation 5 will yield:

$$\Delta K = \Delta\sigma \sqrt{a}\ \beta_T \tag{7}$$

3. CORRECTION FACTORS

Equations 6 and 7 represent stress-intensity-factor ranges for a centrally cracked infinite panel if β_T is unity. For other geometries, β_T must be modified. For various combinations of geometries, β_T will become combinations of different β_i which will account for these separate effects. For example, in the program, β_2 corrects for finite width and β_3 can correct for a crack emanating from a circular hole. Hence, for a crack emanating from a hole in a finite width panel, β_T would be the product of β_2 and β_3. The program provides for up to ten β_i of which only four are active at the present time. Thus, in general,

$$\beta_T = \prod \beta_i \qquad (i = 1,\ 10) \tag{8}$$

The four active correction factors in the program at the present time are explained below:

β_1 - CONSTANT MULTIPLIER

This provides the analyst with the capability to scale loads or modify ΔK by a constant factor

β_2 - FINITE WIDTH TANGENT FUNCTION

This corrects for a finite width plate. The form of this correction is (Reference 4)

$$\beta_2 = \sqrt{\frac{2b}{\pi a} \tan\left(\frac{\pi a}{2b}\right)} \tag{9}$$

where "a" and "b" are as shown in Figure 1.

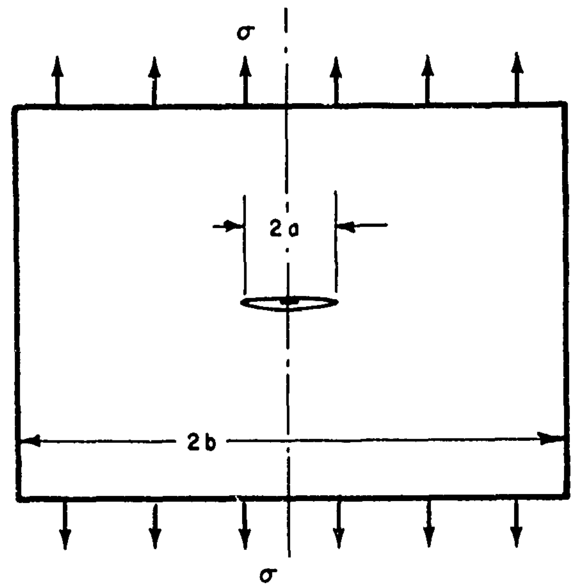

Figure 1. Griffith Crack in a Finite Width Plate

β_3 - TABULAR CORRECTION FACTOR

This permits the analyst to apply correction factors which appear in the literature as discrete data. The form of this correction is

$$\beta_3 = f(a/\ell_c) \tag{10}$$

An example is the crack emanating from a circular hole (Reference 4). In this case, "a" and "ℓ_c" are as shown in Figure 2.

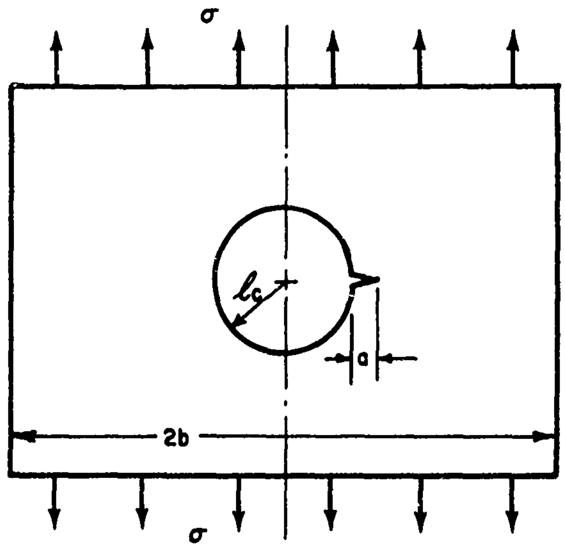

Figure 2. Crack Emanating from a Circular Hole

β_4 - ELLIPTICAL SURFACE FLAW CORRECTION

The expression for the stress intensity factor developed by Irwin (Reference 5) is given as

$$K = \frac{1.1\,\sigma\sqrt{\pi a}}{\left[\Phi^2 - 0.212\,(\sigma/\sigma_{ys})^2\right]^{1/2}} \tag{11}$$

where

$$\Phi = \int_0^{\pi/2} \left[1 - \left(\frac{c^2 - a^2}{c^2}\right) \sin\theta\right]^{1/2} d\theta$$

The geometry of the surface flaw is defined in Figure 3.

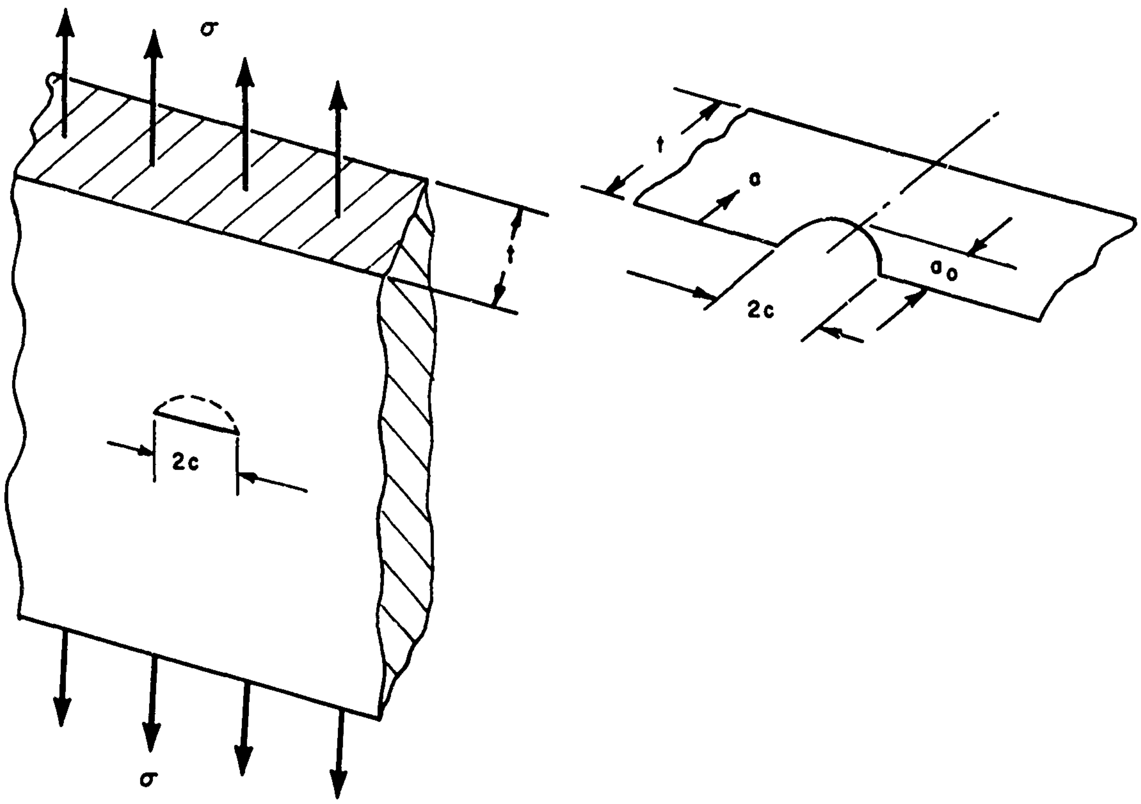

Figure 3. Surface Flaw Geometry

As the surface flaw approaches the back surface of the material, a magnification of the stress intensity factor takes place. This is accounted for by a magnification factor, M_k, which is a function of both a/t and a/2c. The magnification factor used in CRACKS has been obtained from Reference 6 and is included in Figure 4 for various flaw shapes (a/2c values). Although this data has been derived for aluminum, it is in close agreement with the results of Kobayashi (Reference 7) and Smith (Reference 8) for general applications. Hence, Equation 11 may be written as

$$K = 1.1\, M_k\, \sigma \sqrt{\pi a / Q} \qquad (12)$$

where

$$Q = \Phi^2 - 0.212 \left(\frac{\sigma}{\sigma_{ys}}\right)^2 \qquad (13)$$

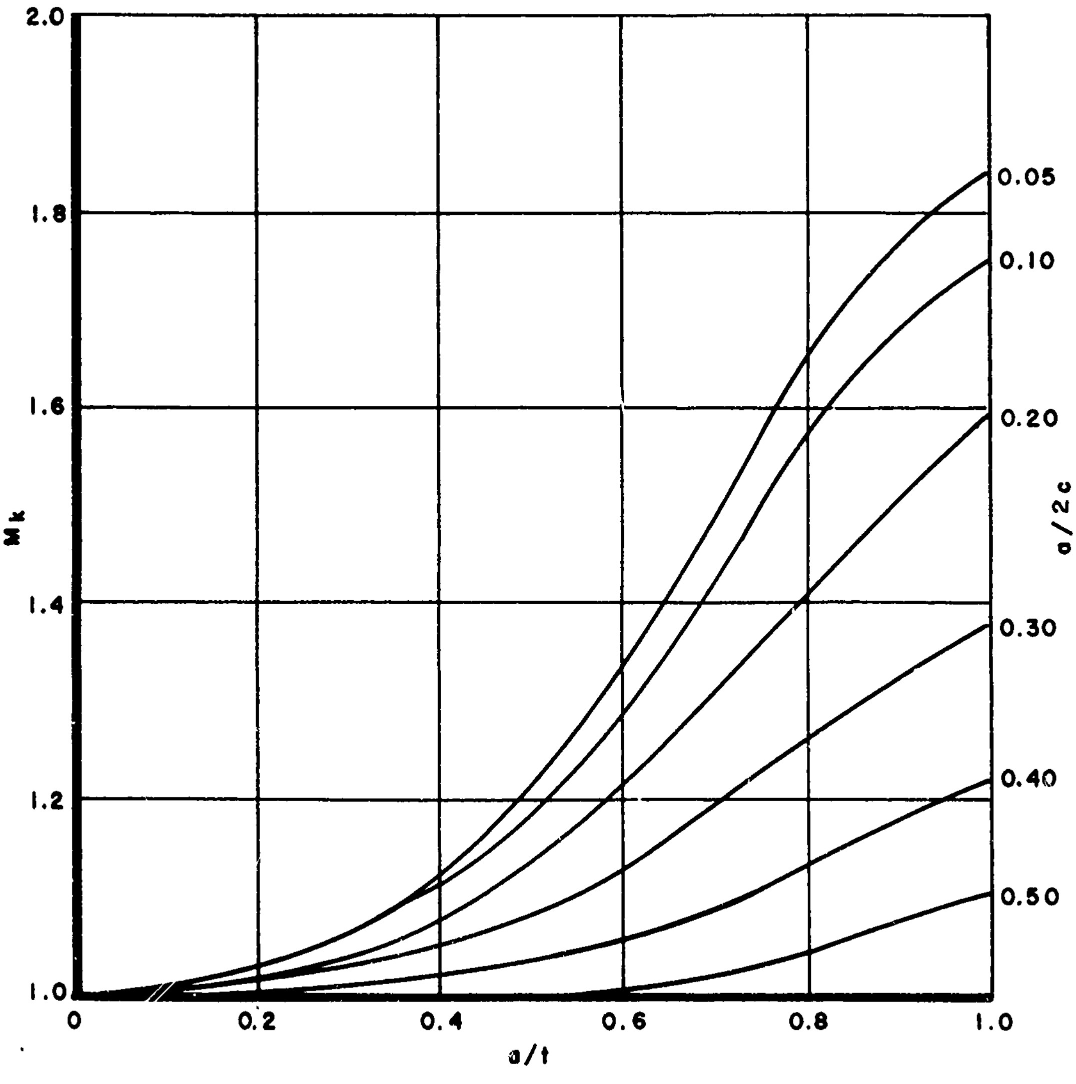

Figure 4. Magnification Factor Curves

Since Q is a function of σ, it is not convenient to develop an equation of the form of Equation 6. It is instead more convenient to obtain K_{max} and K_{min} and thus obtain ΔK. So, from Equations 12 and 13 we obtain

$$K_{max} = 1.1\, M_k\, \sigma_{max} \sqrt{\pi a / Q_{max}} \tag{14 a}$$

$$K_{min} = 1.1\, M_k\, \sigma_{min} \sqrt{\pi a / Q_{min}} \tag{14 b}$$

From these equations we see that the obvious expression for β_4 is

$$\beta_4 = 1.1\, M_k \tag{15}$$

and we can then write

$$\Delta K = \sqrt{\pi a} \left[\frac{Q_{max}}{\sqrt{Q_{max}}} - \frac{Q_{min}}{\sqrt{Q_{min}}} \right] \beta_4 \tag{16}$$

The translation from a surface flaw to a through crack is chosen to be the point when the plastic zone reaches the back face of the material. The value of "a" for which this occurs is given as

$$a_t = t - \frac{1}{2\pi} \left(\frac{K_{max}}{\sigma_{ys}} \right)^2 \tag{17}$$

where K_{max} is defined by Equation 14a. At this point an effective through-crack length is calculated and the program then continues, now using Equation 6 for ΔK, with β_4 set to unity.

SECTION III

COMPUTER PROGRAM FOR CRACK PROPAGATION ANALYSIS (CRACKS)

The program described below was written in FORTRAN IV for the IBM 7044-7094II Direct Coupled System. The program consists of seven subprograms, each of which has a specific task to perform. These subprograms and their functions are:

CRACKS - reads in data, sets up calculations, and prints the results.

F - evaluates crack propagation rate, da/dN.

RK1DES - variable-step Runge-Kutta integration routine which integrates da/dN over each load block.

TBLKUP - linear interpolation scheme for use with β_3.

ELIP2 - routine to evaluate the complete elliptic integral of the second kind to calculate Φ for use in Equation 12.

TIFANY - block data subroutine containing data for Tiffany's M_k curves as a function of a/t and a2c.

TRP2 - parabolic interpolation routine for a function of two variables which is used to determine M_k for Equation 13.

A simplified flow chart depicting the transfer of information from the subprograms discussed above is given in Figure 5.

1. DESCRIPTION

The CRACKS computer program integrates the crack-propagation-rate equation to obtain crack growth versus cycles. The program provides options for the two prevalent forms of this equation (Equations 1 and 2). Many crack geometries may be modeled using the correction factors discussed in Section II, paragraph 3. A transition from a surface flaw to a through crack is provided (Equation 17). As a convenience, the program makes provisions for two forms of spectrum input, maximum and minimum stresses, or stress range and load ratio. The program also has the capability to run multiple problems merely by loading data decks in sequence.

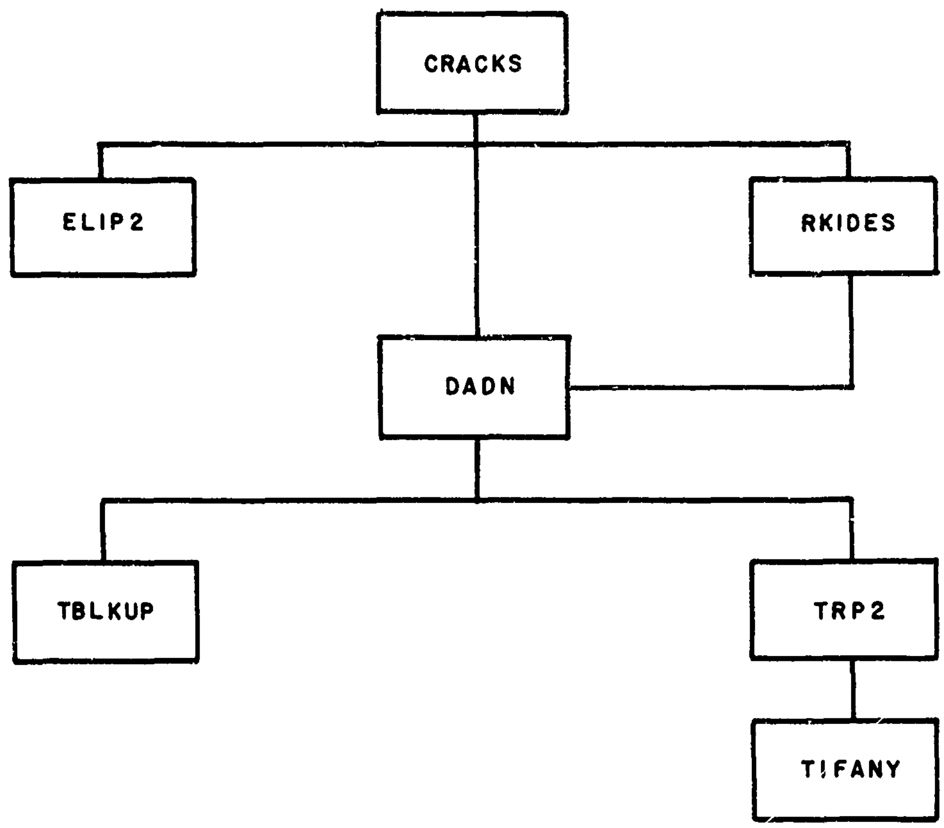

Figure 5. Information Transfer Flow Chart

2. INPUT INSTRUCTIONS

The input to the program consists of four basic sections: analysis selection, material properties, geometry definition, and loading. In addition, there are controls on print interval, repetition of load spectrum, and descriptive data. Detailed instructions on inputting the data cards are given below in the following manner:

a. Card number and contents

b. FORTRAN name for each variable

c. Format of card

d. Description of each variable

Card 1 Descriptive Information

TITLE

FORMAT (14A6)

TITLE - any information to define the problem for the user.

Card 2 Analysis Selection, Material Description

EQN, MATID

FORMAT (A6, 4X, 7A6)

EQN - alphameric indicator governing choice of analysis.

The choices are: FORMAN - use Equations 2 and 6

PARIS - use Equations 1 and 6

NASAF - use Equations 2 and 7

NASAP - use Equations 1 and 7

MATID - alphanumeric identification to label material (may be left blank)

Card 3 Material Properties

C, SMALLN, KSUBC, SIGMAY

FORMAT (4E10.0)

C - material constant in Equations 1 and 2

SMALLN - exponent in Equations 1 and 2

KSUBC - fracture toughness of material

SIGMAY - yield stress of material, need only be input when running a surface flaw analysis.

Card 4 Initial and Allowable Crack Lengths

AZERO, AMAX

FORMAT (2E10.0)

AZERO - initial half crack length

AMAX - allowable half crack length. If zero, program assumes infinite allowable length.

Card 5 Correction Factor Information

BETAL, I, BI, B1I

FORMAT (A4, I1, 5X, 2E10.0)

BETAL - label for correction factors. Alphameric characters, "BETA"

I - indicator for correction factor selection. For permissible values see Table I

BI - variable for correction factor (see Table I)

B1I - secondary variable for correction factor, (see Table I)

If I equals three, a table of points for the correction factor follows the BETA3 card immediately. The format of this card is as follows:

AOVERB, BETATB

FORMAT (2E10.0)

AOVERB - ratio of crack length to characteristic length

BETATB - tabular value of β_3 corresponding to this ratio

Again, note that the BETAO card input must always be present and must be the last BETA card if others are present.

Card 6 Initial Cycle, Number of Applications

NZERO, NFLITE

FORMAT (E10.0, I10)

NZERO - number of the initial cycle for this computer run. NZERO is the cycle corresponding to AZERO.

NFLITE - this defines the number of times the input load spectrum will be applied.

TABLE I

CORRECTION FACTORS

I	Correction Factor	BI	BII
1	Constant (β_1)	Constant value	—
2	Finite Width (β_2)	Plate half width	—
3	Tabular (β_3)	Characteristic length	Number of points in table
4	Surface flaw (β_4)	Flaw half width	Material thickness
5 - 9	Inoperative at present	—	—
0	End of corrections (Must always be present)	—	—

<u>Card 7</u> Load Format Selector

LOADS

FORMAT (A5)

LOADS - alphameric indicator governing choice of input load format.

"SIGMA" - input σ_{max} and σ_{min}

"RANGE" - input $\Delta\sigma$ and R

<u>Card 8</u> Loads and Print Controls

$$\text{LABEL}, \left\langle \begin{matrix}\text{SIGMAX}\\ \text{or}\\ \text{DELTAT}\end{matrix} \right\rangle, \left\langle \begin{matrix}\text{SIGMIN}\\ \text{or}\\ \text{R}\end{matrix} \right\rangle, \text{CYCLES, NINT, NPRINT}$$

FORMAT - (A5, 5E10.0)

LABEL - any five characters to identify load block. May be left blank. After the last load card, a card with "END" in LABEL is required.

SIGMAX - maximum applied tensile stress

DELTAT - applied tensile stress range

SIGMIN - minimum applied tensile stress

R - stress ratio

CYCLES - number of cycles in this load block

NINT - integration interval for this load block. If NINT is zero, the program sets NINT equal to CYCLES.

NPRINT - print interval for this load block. If NPRINT is zero, the program sets NPRINT equal to NINT.

3. RESTRICTIONS

Certain restrictions and limitations must be recognized or the capacity of the program will be exceeded. In general, violation of these restrictions will not result in termination of the computer run. Hence, stacked problems may be salvaged even though an error occurs in one of the first few data decks.

a. Program Capacity

The program will not accept more than 1000 load cards or 100 cards for the tabular correction factor. This is an arbitrary choice of numbers and may be changed by modifying the appropriate DIMENSION statements within the source deck.

b. Print Interval

Because of the variable step nature of the Runge-Kutta integration scheme, it is inconvenient to generate printout at intervals less than the integration interval. Hence, NPRINT is always greater than or equal to NINT.

c. Negative Loads

The theory developed in References 1 and 2 does not permit negative loading. This leads to the requirement that σ_{max}, $\Delta\sigma$, and R must always be greater than or equal to zero.

4. OUTPUT

The output generated by CRACKS is, for the most part, self-explanatory. The first page of output consists of a display of the input data which define the problem. The next section of output consists of a printout of the input load spectrum. If the spectrum is input in terms of maximum and minimum stresses, these are then changed within the program to stress ranges and stress ratio and these are also printed out.

After the problem has been completely specified, the program begins calculating the increase in crack length by integrating either Equation 1 or Equation 2 over each load block and printing results at each print interval requested. This output consists of values for the most pertinent parameters which are valid at the cycle printed out. If the surface flaw correction is not used, M_k and Q from Equation 14 are set equal to unity.

In the course of the calculations, the denominator of Equation 2 is monitored to determine the cycle at which it becomes negative. Since it is possible for the denominator to go negative during an integration interval, the program sets an indicator in the integration routine and returns to the CRACKS program. Here the variables are reset to the values immediately before the denominator became negative. The program then uses these values as starting values and reduces the integration interval. The program then proceeds as before until the denominator again goes negative. This process is repeated until the integration interval is reduced to one cycle. When the denominator goes negative for this integration interval, the cycle number at the onset of instability is available. The final values are then printed out and identified. A similar procedure is followed when using Equation 1 except that the instability criterion becomes K_{max} greater than nine-tenths K_c.

SECTION IV

SUMMARY

An automated analysis for determining crack growth in cyclic loaded structures under variable amplitude loading has been described. In Appendix II an illustrative problem has been presented and the results compared with published data. The results show the program in close agreement with the analytical results and conservative in comparison with the experimental results.

REFERENCES

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2. R. G. Forman, V. E. Kearney and R. M. Engle, Jr., "Numerical Analysis of Crack Propagation in Cyclic-Loaded Structures," JOURNAL OF BASIC ENGINEERING, TRANS. ASME., Series D, Vol. 89, No. 3, 1967, pp 459-464.

3. C. M. Hudson, "Effect of Stress Ratio on Fatigue-Crack Growth in 7075-T6 and 2024-T3 Aluminum Alloy Specimens," NASA TN D-5390, Aug. 1969.

4. P. C. Paris and G. C. Sih, "Stress Analysis of Cracks," FRACTURE TOUGHNESS TESTING AND ITS APPLICATIONS, ASTM-STP381, 1965.

5. FOURTH ANNUAL WORKSHOP IN FRACTURE MECHANICS, Universal Technology Corporation, 1967.

6. J. N. Masters, W. P. Haese, and R. W. Finger, "Investigation of Deep Flaws in Thin Walled Tanks," NASA CR-72606.

7. A. S. Kobayashi, "On the Magnification Factors of Deep Surface Flaws," Structural Development Research Memorandum No. 17, The Boeing Company, Dec. 1965.

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APPENDIX I

PROGRAM SOURCE LISTING

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```
$IBFTC CRACKS  M94,XR7,DECK
C
C                              CRACKS
C
C         A FORTRAN IV COMPUTER PROGRAM FOR CRACK PROPAGATION ANALYSIS.
C
C     THIS PROGRAM IS BASED ON THEORY DEVELOPED IN A PAPER APPEARING IN
C  THE 'JOURNAL OF BASIC ENGINEERING' SEPTEMBER 1967,PAGES 459-464,
C  ENTITLED
C
C         'NUMERICAL ANALYSIS OF CRACK PROPAGATION IN CYCLIC-LOADED
C          STRUCTURES',R.G.FORMAN,V.E.KEARNEY,R.M.ENGLE
C
C     THE PROGRAM ACCEPTS EITHER FORMAN'S EQUATION OR PARIS' EQUATION
C
C                              FORMAN'S EQUATION
C
C         DA/DN = C(DELTA K)**N/((1-R)KSUBC-DELTA K)
C
C                              PARIS' EQUATION
C
C         DA/DN = C(DELTA K)**N
C
C     WHERE
C
C        DELTA K = (DELTA T) * SQRT(PI*A) * BETA
C
C        OR - FOR NASA DATA -
C
C        DELTA K = (DELTA T) * SQRT(A) * BETA
C
C     AND
C         DELTA T =(SIGMA MAX)-(SIGMA MIN)
C         BETA = COMBINATION OF CORRECTION FACTORS.
C
C                              INPUT
C
C  CARD(S)  COLUMNS FORMAT     NAME      DESCRIPTION
C
C    1      1-80    14A6       TITLE     ANY DESCRIPTIVE INFORMATION
C
C    2      1-6     A6         EQN       'PARIS '-USE PARIS' EQUATION.
C                                        'FORMAN'-USE FORMAN'S EQUATION.
C                                        'NASAP'-USE PARIS' EQUATION
C                                        WITH NASA DELTA K.
C                                        'NASAF'-USE FORMAN'S EQUATION
C                                        WITH NASA DELTA K.
C           7-10    4X                   SKIP 4 SPACES
C
C           11-52   7A6        MATID     MATERIAL ID.ANY INFORMATION
C
C    3      1-10    4E10.0     C         MATERIAL CONSTANT IN EQUATIONS
C           11-20              SMALLN    EXPONENT IN EQUATIONS
C           21-30              KSUBC     CRITICAL STRESS INTENSITY FACTOR
C           31-40              SIGMAY    YIELD STRESS
C
C    4      1-10    2E10.0     AZERO     INITIAL HALF CRACK LENGTH
C           11-20              AMAX      MAXIMUM CRACK LENGTH ALLOWED
C
C    5      1-4     A4         BETAL     'BETA'-LABEL FOR CORRECTION
C                                        FACTOR CARDS
C           5       I1         I         CODE FOR CORRECTION FACTORS
```

```
C            6-10    5X                     FIVE BLANKS                        CRAC0062
C            11-20   2E10.0     BI          VARIABLE NEEDED FOR CORRECTION     CRAC0063
C                                           FACTOR                             CRAC0064
C            21-30              BII         VARIABLE NEEDED FOR CORRECTION     CRAC0065
C                                           FACTOR                             CRAC0066
C                                                                              CRAC0067
C***** THE VARIABLES,BI AND BII,TAKE ON DIFFERENT MEANINGS FOR EACH BETACRAC0068
C                                                                              CRAC0069
C          I         CORRECTION             BI             BII                 CRAC0070
C                                                                              CRAC0071
C          1         CONSTANT               CONSTANT       0.                  CRAC0072
C          2         FINITE WIDTH           PLATE WIDTH    0.                  CRAC0073
C          3         TABULAR                CHARACTERISTIC NUMBER OF POINTS    CRAC0074
C                                           LENGTH         IN TABLE(NPTS)      CRAC0075
C                                                                              CRAC0076
C***** THERE WILL BE'NPTS'CARDS TO DEFINE THE TABLE.                          CRAC0077
C                                                                              CRAC0078
C            1-10    2E10.0     AOVERB      A/B RATIOS FOR TABLE               CRAC0079
C            11-20              BETATB      CORRESPONDING 'BETA' VALUES        CRAC0080
C                                                                              CRAC0081
C          4         SURFACE FLAW           FLAW           MATERIAL            CRAC0082
C                                           HALF-WIDTH     THICKNESS           CRAC0083
C          0         END OF CORRECTIONS                                        CRAC0084
C                                                                              CRAC0085
C***** THE 'BETAO' CARD MUST ALWAYS BE PRESENT.IF THERE ARE SEVERAL           CRAC0086
C      CORRECTION FACTORS,IT MUST BE THE LAST'BETA'CARD.IF NO CORRECTIONCRAC0087
C      FACTOR CARDS ARE USED,'BETAO' MUST STILL BE PRESENT.                    CRAC0088
C                                                                              CRAC0089
C                                                                              CRAC0090
C     6      1-10    E10.0      NZERO       INITIAL CYCLE NUMBER               CRAC0091
C            11-20   I10        NFLITE      REPEAT SPECTRUM 'NFLITE' TIMES.    CRAC0092
C                                                                              CRAC0093
C     7      1-5     A5         LOADS       LABEL FOR FORM OF INPUT SPECTRUMCRAC0094
C                                           'SIGMA'-READ CARD(S) 9.            CRAC0095
C                                           'RANGE'-READ CARD(S) 10.           CRAC0096
C                                                                              CRAC0097
C     8      1-5     A5         LABEL       FIVE CHARACTERS                    CRAC0098
C            6-15    5E10.0     SIGMAX      MAXIMUM STRESS                     CRAC0099
C            16-25              SIGMIN      MINIMUM STRESS                     CRAC0100
C            26-35              CYCLES      NO.CYCLES IN LOAD BLOCK            CRAC0101
C            36-45              NINT        INTEGRATION INTERVAL IN CYCLES     CRAC0102
C                                           IF NINT=0,SET NINT=CYCLES.         CRAC0103
C            46-55              NPRINT      PRINT INTERVAL IN CYCLES           CRAC0104
C                                           IF NPRINT=0,SET NPRINT=NINT.       CRAC0105
C***** A MAXIMUM OF 1000 LOAD CARDS IS PERMITTED.                              CRAC0106
C***** GO TO CARD 10.                                                          CRAC0107
C     9      1-5     A5         LABEL       FIVE CHARACTERS                    CRAC0108
C            6-15    5E10.0     DELTAT      DELTA SIGMA(SIGMAX-SIGMIN)         CRAC0109
C            16-25              R           STRESS RATIO(SIGMIN/SIGMAX)        CRAC0110
C            26-35              CYCLES      NO.CYCLES IN LOAD BLOCK            CRAC0111
C            36-45              NINT        INTEGRATION INTERVAL IN CYCLES     CRAC0112
C                                           IF NINT=0,SET NINT=CYCLES.         CRAC0113
C            46-55              NPRINT      PRINT INTERVAL IN CYCLES           CRAC0114
C                                           IF NPRINT=0,SET NPRINT=NINT.       CRAC0115
C***** A MAXIMUM OF 1000 LOAD CARDS IS PERMITTED.                              CRAC0116
C                                                                              CRAC0117
C     10     1-5     A3         END         'END'-TERMINATES PROBLEM INPUT.    CRAC0118
C                                                                              CRAC0119
      INTEGER BLK,END                                                          CRAC0120
      REAL NZERO,NINT,NPRINT,NFINAL,NN,NDEL,NSTRT,NWRITE                       CRAC0121
      REAL NASAF,NASAP                                                         CRAC0122
      REAL KSUBC,KMAX,MSUBK                                                    CRAC0123
```

```
      COMMON /DATA/ B(9),C,SMALLN,DELTAK,KMAX,KSUBC,NPTS,JJ,SIGMAY,EQN,   CRAC0124
     1          IPRC,THICK,AZERO,AMAX,Q,BETA(9),IND(9),PHI,RATIO,SMALLC   CRAC0125
      COMMON/CORFAC/TSUBA(1000),R(1000),ADVERB(100),BETATB(100),MSUBK    CRAC0126
      COMMON/STOP/ISTOP,ISTOPF,IN,A1,DX1,IDX                              CRAC0127
      DIMENSION SIGMAX(1000),SIGMIN(1000),CYCLES(1000),NFINAL(1000),     CRAC0128
     1          NINT(1000),NPRINT(1000),TITLE(14)                         CRAC0129
      DIMENSION LAB(1000),MATID(7)                                        CRAC0130
      DATA   END,LOAD2 /5HEND   ,6HRANGE /                                CRAC0131
      DATA PARIS,FORMAN /6HPARIS ,6HFORMAN/                               CRAC0132
      DATA NASAP,NASAF /6HNASAP ,6HNASAF /                                CRAC0133
C                                                                         CRAC0134
C     READ PROBLEM SPECIFICATIONS                                         CRAC0135
C                                                                         CRAC0136
   10 READ(5,330) TITLE                                                   CRAC0137
      WRITE(6,400) TITLE                                                  CRAC0138
      READ(5,340) EQN,MATID                                               CRAC0139
      READ(5,350) C,SMALLN,KSUBC,SIGMAY                                   CRAC0140
      WRITE(6,410) MATID,C,SMALLN,KSUBC,SIGMAY                            CRAC0141
      READ(5,350) AZERO,AMAX                                              CRAC0142
      IF(AMAX.LE.0.) AMAX=1.0E37                                          CRAC0143
      WRITE(6,420) AZERO                                                  CRAC0144
      IPRC=0                                                              CRAC0145
      DO 20 I=1,9                                                         CRAC0146
      IND(I)=0                                                            CRAC0147
   20 BETA(I)=1.0                                                         CRAC0148
      IF(EQN.EQ.PARIS.OR.EQN.EQ.FORMAN) WRITE(6,650)                      CRAC0149
      IF(EQN.EQ.NASAP.OR.EQN.EQ.NASAF ) WRITE(6,660)                      CRAC0150
C                                                                         CRAC0151
C     READ CORRECTION FACTOR SPECIFICATIONS                               CRAC0152
C                                                                         CRAC0153
   30 READ(5,370) BETAL,I,BI,B1I                                          CRAC0154
      IF(I.EQ.0) GO TO 100                                                CRAC0155
      GO TO (40,50,60,70,80,80,80,80,80),I                                CRAC0156
   40 BETA(I)=BI                                                          CRAC0157
      WRITE(6,450) BETA(I)                                                CRAC0158
      IND(I)=I                                                            CRAC0159
      GO TO 30                                                            CRAC0160
   50 IND(I)=I                                                            CRAC0161
      B(I)=BI                                                             CRAC0162
      WRITE(6,610) B(I)                                                   CRAC0163
      GO TO 30                                                            CRAC0164
   60 B(I)=BI                                                             CRAC0165
      IND(I)=I                                                            CRAC0166
      NPTS=B1I+0.5                                                        CRAC0167
      WRITE(6,620) B(I)                                                   CRAC0168
      IF(NPTS.LE.0.OR.NPTS.GT.100) GO TO 90                               CRAC0169
      READ(5,390) (ADVERB(I),BETATB(I),I=1,NPTS)                          CRAC0170
      WRITE(6,460)(ADVERB(I),BETATB(I),I=1,NPTS)                          CRAC0171
      GO TO 30                                                            CRAC0172
   70 B(I)=BI                                                             CRAC0173
      THICK=B1I                                                           CRAC0174
      RATIO=AZERO/(2.0*B(I))                                              CRAC0175
      SMALLK=(B(I)**2-AZERO**2)/B(I)**2                                   CRAC0176
      CK=1.-SMALLK**2                                                     CRAC0177
      CKSQD=CK*CK                                                         CRAC0178
      CALL CELI2(PHIO,SMALLK,1.0,CKSQD,IER)                               CRAC0179
      PHI=PHIO                                                            CRAC0180
      IPRC=1                                                              CRAC0181
      IND(I)=I                                                            CRAC0182
      WRITE(6,630) B(I),THICK                                             CRAC0183
      GO TO 30                                                            CRAC0184
   80 CONTINUE                                                            CRAC0185
```

```
      GO TO 30
   90 WRITE(6,640)
      GO TO 10
C
C     READ CONTROL SPECIFICATIONS
C
  100 READ(5,360) NZERO,NFLITE
      WRITE(6,430) NZERO
      WRITE(6,440) NFLITE
C
C     READ LOAD SPECTRUM SPECIFICATIONS
C
      READ(5,330) LOADS
      BLK=1
      IF(LOADS.EQ.LOAD2) GO TO 140
C
C     LOAD SPECTRUM IN TERMS OF MAX AND MIN STRESSES
C
      READ(5,380) LAB(BLK),SIGMAX(BLK),SIGMIN(BLK),CYCLES(BLK),NINT(BLK)
     1,            NPRINT(BLK)
C
C     INTEGRATION INTERVAL CANNOT EXCEED BLOCK SIZE
C
      IF(NINT(BLK).GT.CYCLES(BLK)) NINT(BLK)=CYCLES(BLK)
      IF(NINT(BLK).EQ.0.) NINT(BLK)=CYCLES(BLK)
      NFINAL(BLK)=NZERO+CYCLES(BLK)
  110 BLK=BLK+1
      READ(5,380) LAB(BLK),SIGMAX(BLK),SIGMIN(BLK),CYCLES(BLK),NINT(BLK)
     1,            NPRINT(BLK)
      IF(LAB(BLK).EQ.END) GO TO 120
C
C     INTEGRATION INTERVAL CANNOT EXCEED BLOCK SIZE
C
      IF(NINT(BLK).GT.CYCLES(BLK)) NINT(BLK)=CYCLES(BLK)
      IF(NINT(BLK).EQ.0.) NINT(BLK)=CYCLES(BLK)
      NFINAL(BLK)=NFINAL(BLK-1)+CYCLES(BLK)
      IF(NPRINT(BLK).EQ.0.) NPRINT(BLK)=NINT(BLK)
      GO TO 110
  120 BLK=BLK-1
      WRITE(6,470)
      LINE=0
      DO 130 I=1,BLK
      WRITE(6,480)LAB(I),I,CYCLES(I),NFINAL(I),SIGMAX(I),SIGMIN(I),
     1             NINT(I)
C
C     THEORY DOES NOT RECOGNIZE EFFECTS OF NEGATIVE LOADING
C
      IF(SIGMIN(I).LT.0.)SIGMIN(I)=0.
      LINE=LINE+1
      IF(LINE.GT.55) LINE=0
      IF(LINE.EQ.0) WRITE(6,470)
C
C     CONVERT STRESSES TO RANGE AND RATIO
C
      TSUBA(I)=SIGMAX(I)-SIGMIN(I)
      R(I)=SIGMIN(I)/SIGMAX(I)
  130 CONTINUE
      GO TO 170
C
C     LOAD SPECTRUM IN TERMS OF STRESS RANGE AND STRESS RATIO
C
  140 READ(5,380) LAB(BLK),TSUBA(BLK),R(BLK),CYCLES(BLK),NINT(BLK),
```

```
     1             NPRINT(BLK)
C
C     INTEGRATION INTERVAL CANNOT EXCEED BLOCK SIZE
C
      IF(NINT(BLK).GT.CYCLES(BLK)) NINT(BLK)=CYCLES(BLK)
      IF(NINT(BLK).EQ.0.) NINT(BLK)=CYCLES(BLK)
      NFINAL(BLK)=NZERO+CYCLES(BLK)
      IF(NPRINT(BLK).EQ.0.) NPRINT(BLK)=NINT(BLK)
  150 BLK=BLK+1
      READ(5,380) LAB(BLK),TSUBA(BLK),R(BLK),CYCLES(BLK),NINT(BLK),
     1             NPRINT(BLK)
      IF(LAB(BLK).EQ.END) GO TO 160
C
C     INTEGRATION INTERVAL CANNOT EXCEED BLOCK SIZE
C
      IF(NINT(BLK).GT.CYCLES(BLK)) NINT(BLK)=CYCLES(BLK)
      IF(NINT(BLK).EQ.0.) NINT(BLK)=CYCLES(BLK)
      NFINAL(BLK)=NFINAL(BLK-1)+CYCLES(BLK)
      IF(NPRINT(BLK).EQ.0.) NPRINT(BLK)=NINT(BLK)
      GO TO 150
  160 BLK=BLK-1
  170 WRITE(6,500)
      LINE=0
      DO 180 I=1,BLK
      WRITE(6,490)LAB(I),I,CYCLES(I),NFINAL(I),TSUBA(I),R(I),NINT(I)
C
C     THEORY DOES NOT RECOGNIZE EFFECTS OF NEGATIVE LOADING
C
      IF(R(I).LT.0.) R(I)=0.
      LINE=LINE+1
      IF(LINE.GT.55) LINE=0
      IF(LINE.EQ.0) WRITE(6,500)
  180 CONTINUE
      ISTOP=0
      ISTOPF=0
      IDX=0
      DX1=0.
      A=AZERO
      A1=AZERO
C
C     REPEAT INPUT SPECTRUM  NFLITE  TIMES
C
      DO 320 NFLT=1,NFLITE
      WRITE(6,510) NFLT,A
      IF(EQN.EQ.PARIS.OR.EQN.EQ.NASAP) GO TO 190
      WRITE(6,520)
      GO TO 200
  190 WRITE(6,530)
  200 IN=NZERO
      NN=NZERO
      LINES=0
      IF(IPRC.EQ.0) WRITE(6,560)
      IF(IPRC.NE.0) WRITE(6,570)
C
C     DO LOOP FOR LOAD BLOCKS
C
      DO 310 JJ=1,BLK
      JJJ=1
      DX=NINT(JJ)
  210 IF(JJ.GT.1) GO TO 220
      NSTRT=NZERO
      GO TO 230
```

```
  220 NSTRT=NFINAL(JJ-1)
  230 NWRITE=NSTRT+FLOAT(JJJ)*NPRINT(JJ)
      IF((NN+NINT(JJ)).LE.NFINAL(JJ)) GO TO 250
      NDEL=NN+NINT(JJ)-NFINAL(JJ)
      DX= NINT(JJ)-NDEL
      IF(ISTOPF.EQ.0) GO TO 250
  240 IF(DX1.GT.1.00) ISTOPF=0
      DX=DX1
      NN=IN
      A=A1
      ISTOP=0
  250 CYC=NN
C
C     INTEGRATE OVER ONE INTERVAL
C
      CALL RK1DES(CYC,A,DX)
      IF(ISTOPF.EQ.1) GO TO 240
      IF(ISTOP.NE.0) GO TO 10
      NN=CYC
      IF(NN.NE.NWRITE) GO TO 280
C
C     PRINT RESULTS AT EACH PRINT INTERVAL
C
      CALL F(CYC,A,DADN)
      IF(IPRC.NE.0) GO TO 260
      WRITE(6,540) NN,A,DADN,DELTAK,KMAX,MSUBK,Q
      GO TO 270
  260 WRITE(6,550) NN,A,SMALLC,DADN,DELTAK,KMAX,MSUBK,Q
  270 JJJ=JJJ+1
      LINES=LINES+1
      IF(LINES.EQ.50)LINES=0
      IF(LINES.EQ.0.AND.EQN.EQ.FORMAN) WRITE(6,580)
      IF(LINES.EQ.0.AND.EQN.EQ.NASAF ) WRITE(6,580)
      IF(LINES.EQ.0.AND.EQN.EQ.PARIS) WRITE(6,590)
      IF(LINES.EQ.0.AND.EQN.EQ.NASAP) WRITE(6,590)
      IF(LINES.EQ.0.AND.IPRC.EQ.0) WRITE(6,560)
      IF(LINES.EQ.0.AND.IPRC.NE.0) WRITE(6,570)
      IF(NN.EQ.NFINAL(JJ)) GO TO 310
      GO TO 210
C
C     CHECK FOR END OF LOAD BLOCK AND PRINT RESULTS
C
  280 IF(NN.LT.NFINAL(JJ)) GO TO 210
      CALL F(CYC,A,DADN)
      IF(IPRC.NE.0) GO TO 290
      WRITE(6,540) NN,A,DADN,DELTAK,KMAX,MSUBK,Q
      GO TO 300
  290 WRITE(6,550) NN,A,SMALLC,DADN,DELTAK,KMAX,MSUBK,Q
  300 LINES=LINES+1
      IF(LINES.EQ.50)LINES=0
      IF(LINES.EQ.0.AND.EQN.EQ.FORMAN) WRITE(6,580)
      IF(LINES.EQ.0.AND.EQN.EQ.NASAF ) WRITE(6,580)
      IF(LINES.EQ.0.AND.EQN.EQ.PARIS) WRITE(6,590)
      IF(LINES.EQ.0.AND.EQN.EQ.NASAP) WRITE(6,590)
      IF(LINES.EQ.0.AND.IPRC.EQ.0) WRITE(6,560)
      IF(LINES.EQ.0.AND.IPRC.NE.0) WRITE(6,570)
  310 CONTINUE
      GROWTH=A-AZERO
      WRITE(6,600) NFLT,A,GROWTH
  320 CONTINUE
C     LOOK FOR ANOTHER PROBLEM
C
```

```
      GO TO 10                                                          CRAC0372
  330 FORMAT(14A6)                                                      CRAC0373
  340 FORMAT(A6,4X,7A6)                                                 CRAC0374
  350 FORMAT(6E10.0)                                                    CRAC0375
  360 FORMAT(E10.0,I10)                                                 CRAC0376
  370 FORMAT(A4,I1,5X,2E10.0)                                           CRAC0377
  380 FORMAT(A5,5E10.0)                                                 CRAC0378
  390 FORMAT(2E10.0)                                                    CRAC0379
  400 FORMAT(1H110X14A6)                                                CRAC0380
  410 FORMAT(1H010X18HMATERIAL CONSTANTS6X7A6/11X3HC =E16.8,5X8HSMALLN =CRAC0381
     1F5.2,5X7HKSUBC =E16.8,5X14HYIELD STRESS =E16.8)                   CRAC0382
  420 FORMAT(1H010X27HINITIAL HALF CRACK LENGTH =  E16.8)               CRAC0383
  430 FORMAT(1H010X22HINITIAL CYCLE NUMBER =F11.3)                      CRAC0384
  440 FORMAT(1H010X21HREPEAT INPUT SPECTRUM,I5,7H TIMES   )             CRAC0385
  450 FORMAT(1H010X34HBETA(1)-CONSTANT CORRECTION FACTOR /19X9HBETA(1) =CRAC0386
     1       E16.8)                                                     CRAC0387
  460 FORMAT(1H013X3HA/B16X7HBETA(3)//(8XE15.8,5XE15.8))                CRAC0388
  470 FORMAT(1H112X4HLOAD11X9HNUMBER OF11X9HNUMBER OF18X5HSIGMA20X5HSIGMCRAC0389
     1A14X11HINTEGRATION/13X5HBLOCK10X10HCYCLES PER10X8HCYCLE AT19X3HMAXCRAC0390
     222X3HMIN16X8HINTERVAL/28X10HLOAD BLOCK10X12HEND OF BLOCK59X8H(CYCLCRAC0391
     3ES)//)                                                            CRAC0392
  480 FORMAT(2XA5,6XI5,10XF11.3,10XF11.3,15XF10.2,13XF10.2,10XF11.3)    CRAC0393
  490 FORMAT(2XA5,6XI5,10XF11.3,10XF11.3,15XF10.2,16XF6.3, 10XF11.3)    CRAC0394
  500 FORMAT(1H112X4HLOAD11X9HNUMBER OF11X9HNUMBER OF18X5HDELTA22X1HR16XCRAC0395
     111HINTEGRATION/13X5HBLOCK10X10HCYCLES PER10X8HCYCLE AT19X5HSIGMA39CRAC0396
     2X8HINTERVAL/28X10HLOAD BLOCK10X12HEND OF BLOCK59X8H(CYCLES)//)    CRAC0397
  510 FORMAT(1H15X35HCRACK LENGTH AT BEGINNING OF FLIGHT I5,3H ISF10.5/)CRAC0398
  520 FORMAT(1H040X50HCRACK PROPAGATION ANALYSIS USING FORMAN'S EQUATIONCRAC0399
     1 /44X44HDA/DN=C*(DELTA K)**N/((1-R)*KSUBC-DELTA K)  )             CRAC0400
  530 FORMAT(1H041X48HCRACK PROPAGATION ANALYSIS USING PARIS' EQUATION /CRAC0401
     1  55X23HDA/DN=C*(DELTA K)**N    )                                 CRAC0402
  540 FORMAT(1XF11.3,13XF9.5,13XE15.8,13XF10.2,16XF10.2,4XF5.3,5XF6.3)  CRAC0403
  550 FORMAT(1XF11.3,13XF9.5,2XF9.5,2XE15.8,13XF10.2,16XF10.2,4XF5.3,5X CRAC0404
     1       F6.3)                                                      CRAC0405
  560 FORMAT(1H03X5HCYCLE20X1HA22X5HDA/DN21X7HDELTA K19X5HK MAX6X5HMSUBKCRAC0406
     1       8X1HQ//)                                                   CRAC0407
  570 FORMAT(1H03X5HCYCLE20X1HA10X1HC11X5HDA/DN21X7HDELTA K19X5HK MAX   CRAC0408
     1       6X5HMSUBK8X1HQ//)                                          CRAC0409
  580 FORMAT(1H140X50HCRACK PROPAGATION ANALYSIS USING FORMAN'S EQUATIONCRAC0410
     1 /44X44HDA/DN=C*(DELTA K)**N/((1-R)*KSUBC-DELTA K)  )             CRAC0411
  590 FORMAT(1H141X48HCRACK PROPAGATION ANALYSIS USING PARIS' EQUATION /CRAC0412
     1  55X23HDA/DN=C*(DELTA K)**N    )                                 CRAC0413
  600 FORMAT(1H010X36HCRACK LENGTH AT END OF FLIGHT NUMBER I5,3H ISF10.5CRAC0414
     1/      11X21HTOTAL CRACK GROWTH IS F10.5)
  610 FORMAT(1H010X38HBETA(2)-FINITE WIDTH CORRECTION FACTOR /19X42HBETACRAC0416
     1(2) = SQRT(2/(PI*A/B)*TAN(PI*(A/B)/2)) /19X12HWHERE....B = E16.8) CRAC0417
  620 FORMAT(1H010X32HBETA(3)-TABULAR FUNCTION OF A/B  /19X12HWHERE....BCRAC0418
     1 = E16.8)                                                         CRAC0419
  630 FORMAT(1H010X39HBETA(4)-SURFACE CRACK CORRECTION FACTOR /         CRAC0420
     1       19X51HBETA(4)=1.1/SQRT(PHI**2-0.212*(DELTA T/SIGMA Y)**2)/ CRAC0421
     219X51HWHERE....PHI=E(K,PI/2),K=((B**2-A**2)/B**2) AND B = E16.8  /CRAC0422
     324X62HE(K,PI/2) IS THE COMPLETE ELLIPTIC INTEGRAL OF THE SECOND KICRAC0423
     4ND/19X26HMATERIAL THICKNESS.....T = E16.8)                        CRAC0424
  640 FORMAT(1H010X33HINPUT ERROR,NPTS=0,OR NPTS.GT.100 )               CRAC0425
  650 FORMAT(1H010X36HCORRECTION FACTORS USED FOR DELTA K  //11X60HDELTACRAC0426
     1 K =(DELTA T)*SQRT(PI*A)*BETA(1)*BETA(2)*...BETA(I)             )CRAC0427
  660 FORMAT(1H010X36HCORRECTION FACTORS USED FOR DELTA K  //11X60HDELTACRAC0428
     1 K =(DELTA T)*SQRT( A  )*BETA(1)*BETA(2)*...BETA(I)             )CRAC0429
      END                                                               CRAC0430
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```
$IBFTC DADN    M94,XR7,DECK
      SUBROUTINE F(N,A,DADN)
      COMMON /DATA/ B(9),C,SMALLN,DELTAK,KMAX,KSUBC,NPTS,JJ,SIGMAY,EQN,
     1        IPRC,THICK,AZERO,AMAX,Q,BETA(9),IND(9),PHI,RATIO,SMALLC
      COMMON/CORFAC/TSUBA(1000),R(1000),AOVERB(100),BETATB(100),MSUBK
      COMMON/STOP/ISTOP,ISTOPF,IN,A1,DX1,IDX
      COMMON / MKCURV / MK(1000)
      REAL MK,MSUBK,MSUBK1
      REAL NASAF,NASAP
      REAL KSUBC,N,KMAX,KMAX1
      REAL KMIN
      REAL IN,INN
      DATA PI/3.1415926/
      DATA PARIS,FORMAN /6HPARIS ,6HFORMAN/
      DATA NASAP,NASAF /6HNASAP ,6HNASAF /
      BETAT=1.0
      MSUBK=1.0
      Q=0.0
      SMALLC=A/(2.0*RATIO)
      DO 70 I=1,9
      J=IND(I)
      IF(J.EQ.0) GO TO 70
      GO TO (60,10,20,40,50,50,50,50,50),J
   10 IF(IPRC.NE.0) GO TO 70
      SMALLK=A/B(J)
      IF(SMALLK.GT.1.0) GO TO 320
      BETA(J)=SQRT(2./(PI*SMALLK)*TAN(PI*SMALLK/2.))
      GO TO 60
   20 SMALLK=A/B(J)
   30 BETA(J)=TBLKUP(AOVERB,BETATB,NPTS,100,SMALLK)
      GO TO 60
   40 ATRANS=THICK-(((KMAX/SIGMAY)**2)/(2.0*PI))
      IF(A.GE.ATRANS) GO TO 340
      AOVERT = A/THICK
      MSUBK = TRP2(MK,AOVERT,RATIO,1)
      BETA(J)=1.1*MSUBK
      GO TO 60
   50 CONTINUE
   60 BETAT=BETAT*BETA(J)
   70 CONTINUE
      IF(IPRC.EQ.0) GO TO 80
C
C     Q = SHAPE FACTOR FOR SURFACE CRACKS
C
      SIGMAX=TSUBA(JJ)/(1.0-R(JJ))
      SIGMIN=SIGMAX-TSUBA(JJ)
      QMAX=PHI**2-0.212*(SIGMAX/SIGMAY)**2
      Q=QMAX
      QMIN=PHI**2-0.212*(SIGMIN/SIGMAY)**2
   80 IF(EQN.EQ.NASAP.OR.EQN.EQ.NASAF) GO TO 100
C
C     DELTA K USING FORMAN'S FORM AND CONSTANTS
C
      IF(IPRC.NE.0) GO TO 90
      DELTAK=TSUBA(JJ)*SQRT(PI*A)*BETAT
      KMAX=DELTAK/(1.0-R(JJ))
      GO TO 120
   90 KMAX=SIGMAX*SQRT(PI*A/QMAX)*BETAT
      KMIN=SIGMIN*SQRT(PI*A/QMIN)*BETAT
      DELTAK=KMAX-KMIN
      GO TO 120
C
```

```
C     DELTA K USING HUDSON'S FORM AND CONSTANTS
C
  100 IF(IPRC.NE.0) GO TO 110
      DELTAK=TSUBA(JJ)*SQRT(A)*BETAT
      KMAX=DELTAK/(1.0-R(JJ))
      GO TO 120
  110 KMAX=SIGMAX*SQRT( A  /QMAX)*BETAT
      KMIN=SIGMIN*SQRT( A  /QMIN)*BETAT
      DELTAK=KMAX-KMIN
  120 IF(A.GT.AMAX) GO TO 360
      IF(EQN.EQ.PARIS.OR.EQN.EQ.NASAP) GO TO 130
      DENOM=(1.0-R(JJ))*KSUBC-DELTAK
      IF(DENOM.LE.0.) GO TO 150
      GO TO 140
  130 DELKC=0.9*KSUBC-KMAX
      IF(DELKC.LE.0.) GO TO 150
      DENOM=1.0
  140 DADN=(C*DELTAK**SMALLN)/DENOM
      IN=N
      GO TO 290
  150 ISTOP=1
      IF(ISTOPF.NE.0) GO TO 210
      ISTOPF=ISTOPF+1
      IF(IDX.NE.0) GO TO 180
      INN=N
      IF(EQN.EQ.FORMAN.OR.EQN.EQ.NASAF) WRITE(6,160) INN
  160 FORMAT(1H036H((1-R)KSUBC-DELTAK) WENT NEGATIVE ATF11.3,7H CYCLES /
     11H010X37HBEGIN SEARCH FOR MORE ACCURATE VALUES  /11X15HSTARTING VA
     2LUES//)
      IF(EQN.EQ.PARIS.OR.EQN.EQ.NASAP) WRITE(6,170)INN
  170 FORMAT(1H037HK MAX BECAME GREATER THAN .9*KSUBC ATF11.3,7H CYCLES/
     11H010X37HBEGIN SEARCH FOR MORE ACCURATE VALUES  /11X15HSTARTING VA
     2LUES//)
      GO TO 200
  180 WRITE(6,190) IDX
  190 FORMAT(1H010X16HVALUES FOR DX = I4,7H CYCLES  //)
  200 WRITE(6,220) IN,A1,DA1,DEL1,KMAX1,MSUBK1,Q1
      GO TO 240
  210 WRITE(6,230)
      WRITE(6,220) IN,A1,DA1,DEL1,KMAX1,MSUBK1,Q1
  220 FORMAT(2XF11.3,13XF9.5,13XE15.8,13XF10.2,16XF10.2,4XF5.3,5XF6.3)
  230 FORMAT(1H010X41H******VALUES AT ONSET OF INSTABILITY*****   ///)
      ISTOPF=2
      RETURN
  240 DELTAN=N-IN
      IF(DELTAN.LE.1.) GO TO 210
      NDEL=ALOG10(DELTAN)
      IF(NDEL.EQ.0) GO TO 250
      IF(NDEL.GT.6) GO TO 300
      GO TO (250,250,250,260,270,280),NDEL
  250 DX1=1.
      IDX=DX1+0.5
      RETURN
  260 DX1=10.
      IDX=DX1+0.5
      RETURN
  270 DX1=100.
      IDX=DX1+0.5
      RETURN
  280 DX1=1000.
      IDX=DX1+0.5
      RETURN
```

```
290 A1=A                                                                DADN0124
    DA1=DADN                                                            DADN0125
    DEL1=DELTAK                                                         DADN0126
    KMAX1=KMAX                                                          DADN0127
    Q1=Q                                                                DADN0128
    MSUBK1=MSUBK                                                        DADN0129
    RETURN                                                              DADN0130
300 WRITE(6,310)                                                        DADN0131
310 FORMAT(1H06X101HSOMETHING IS RADICALLY WRONG.THE CRITICAL VALUE OFDADN0132
   1 N CAN ONLY BE DETERMINED WITHIN ONE MILLION CYCLES  )              DADN0133
    ISTOPF=2                                                            DADN0134
    RETURN                                                              DADN0135
320 WRITE(6,330)                                                        DADN0136
330 FORMAT(1H075HCRACK LENGTH,A,IS GREATER THAN PLATE WIDTH,B.THIS IS  DADN0137
   1PHYSICALLY IMPOSSIBLE.  )                                           DADN0138
    GO TO 390                                                           DADN0139
340 AEFF=BETAT**2*ATRANS                                                DADN0140
    WRITE(6,350) AEFF                                                   DADN0141
350 FORMAT(1X130(1H*)/35X41HTRANSITION TO A THROUGH CRACK OF LENGTH    DADN0142
   1        F9.5,7H INCHES/1X130(1H*))                                  DADN0143
    IND(4)=0                                                            DADN0144
    A=AEFF                                                              DADN0145
    IPRC=0                                                              DADN0146
    GO TO 80                                                            DADN0147
360 WRITE(6,370)                                                        DADN0148
370 FORMAT(1H1130(1H*)/14X104HTHE CRACK GROWTH EXCEEDS THE MAXIMUM ALLDADN0149
   1OWED LENGTH.    EXAMINE THE PROBLEM FOR POSSIBLE REFORMULATION.  /DADN0150
   21X130(1H*))                                                         DADN0151
    WRITE(6,380)                                                        DADN0152
380 FORMAT(1H03X5HCYCLE20X1HA22X5HDA/DN21X7HDELTA K19X5HK MAX6X5HMSUBKDADN0153
   1        8X1HQ//)                                                    DADN0154
    WRITE(6,220) IN,A1,DA1,DEL1,KMAX1,MSUBK1,Q1                         DADN0155
390 ISTOP=1                                                             DADN0156
    ISTOPF=2                                                            DADN0157
    RETURN                                                              DADN0158
    END                                                                 DADN0159
```

```
$IBFTC RK1DES  M94,XR7,DECK
      SUBROUTINE RK1DES(X,Y,DX)
      COMMON/STOP/ISTOP,ISTOPF,IN,A1,DX1,IDX
   10 X0=X
      X=X+DX
      H=DX
   20 IF(ABS(H).GT.ABS(X-X0)) H=X-X0
   30 Y0=Y
      HT=H
      XT=X0
      RMAXP=1.E37
   40 YT=Y0
      ASSIGN 50 TO K
      GO TO 100
   50 CONTINUE
   60 YP=Y
   70 HT=0.5*H
      ASSIGN 80 TO K
      GO TO 100
   80 CONTINUE
   90 YT=Y
      XT=X0+HT
      ASSIGN 150 TO K
  100 CALL F(XT,YT,P0)
      IF(ISTOP.NE.0) RETURN
  110 Y=YT+0.5*HT*P0
      CALL F(XT+0.5*HT,Y,P1)
      IF(ISTOP.NE.0) RETURN
  120 Y=YT+0.5*HT*P1
      CALL F(XT+0.5*HT,Y,P2)
      IF(ISTOP.NE.0) RETURN
  130 Y=YT+HT*P2
      CALL F(XT+HT,Y,P3)
      IF(ISTOP.NE.0) RETURN
  140 Y=YT+HT*(P0+2.*(P1+P2)+P3)/6.
      GO TO K,(50,80,150)
  150 RMAX=0.
  160 RMAX=AMAX1(RMAX,0.07*ABS((Y-YP)/Y))
      IF((RMAX.GT.1.E-06).AND.(RMAX.LT.RMAXP)) GO TO 170
      X0=X0+H
      IF(X0.EQ.X) RETURN
      IF((RMAX.LT.1.E-07). OR.(RMAX.GT.RMAXP)) H=H+H
      GO TO 20
  170 H=HT
      XT=X0
  180 YP=YT
  190 YT=Y0
      RMAXP=RMAX
      GO TO 70
      END
```

```
$IBFTC TBLKUP  M94,XR7,DECK
      FUNCTION TBLKUP(X,Y,N,NMAX,ARG)
       DIMENSION X(NMAX),Y(NMAX)
      DO 10 I=1,N
      IF(X(I)-ARG) 10,20,20
   10 CONTINUE
      I=N
   20 IF(I-1)30,30,40
   30 I=2
   40 SLOPE=(Y(I)-Y(I-1))/(X(I)-X(I-1))
      TBLKUP=SLOPE*(ARG-X(I-1))+Y(I-1)
      RETURN
      END
```

```
$IBFTC ELIP2   M94,XR7,DECK
C
C     ..................................................................
C
C        SUBROUTINE CELI2
C
C        PURPOSE
C           COMPUTES THE GENERALIZED COMPLETE ELLIPTIC INTEGRAL OF
C           SECOND KIND.
C
C        USAGE
C           CALL CELI2(RES,AK,A,B,IER)
C
C        DESCRIPTION OF PARAMETERS
C           RES    - RESULT VALUE
C           AK     - MODULUS (INPUT)
C           A      - CONSTANT TERM IN NUMERATOR
C           B      - FACTOR OF QUADRATIC TERM IN NUMERATOR
C           IER    - RESULTANT ERROR CODE WHERE
C                    IER=0  NO ERROR
C                    IER=1  AK NOT IN RANGE -1 TO +1
C
C        REMARKS
C           FOR AK = +1,-1 THE RESULT VALUE IS SET TO 1.E75 IF B IS
C           POSITIVE, TO -1.E75 IF B IS NEGATIVE.
C           SPECIAL CASES ARE
C           K(K) OBTAINED WITH A = 1, B = 1
C           E(K) OBTAINED WITH A = 1, B = CK*CK WHERE CK IS
C           COMPLEMENTARY MODULUS.
C           B(K) OBTAINED WITH A = 1, B = 0
C           D(K) OBTAINED WITH A = 0, B = 1
C           WHERE K, E, B, D DEFINE SPECIAL CASES OF THE GENERALIZED
C           COMPLETE ELLIPTIC INTEGRAL OF SECOND KIND IN THE USUAL
C           NOTATION, AND THE ARGUMENT K OF THESE FUNCTIONS MEANS
C           THE MODULUS.
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           NONE
C
C        METHOD
C           DEFINITION
C           RES=INTEGRAL((A+B*T*T)/(SQRT((1+T*T)*(1+(CK*T)**2))*(1+T*T))
C           SUMMED OVER T FROM 0 TO INFINITY).
C           EVALUATION
C           LANDENS TRANSFORMATION IS USED FOR CALCULATION.
C           REFERENCE
C           R.BULIRSCH, 'NUMERICAL CALCULATION OF ELLIPTIC INTEGRALS
C           AND ELLIPTIC FUNCTIONS', HANDBOOK SERIES SPECIAL FUNCTIONS,
C           NUMERISCHE MATHEMATIK VOL. 7, 1965, PP. 78-90.
C
C     ..................................................................
C
      SUBROUTINE CELI2(RES,AK,A,B,IER)
      IER=0
C
C     TEST RANGE
C
      CK=AK*AK
      IF(CK-1.) 20,20,10
   10 IER=1
      RETURN
C
```

```
C     COMPUTE COMPLEMENTARY MODULUS                                     ELIP0062
C                                                                       ELIP0063
   20 GEO=SQRT(1.0-CK)                                                  ELIP0064
      IF(GEO) 70,30,70                                                  ELIP0065
C                                                                       ELIP0066
C     SET RESULT VALUE = OVERFLOW                                       ELIP0067
C                                                                       ELIP0068
   30 IF(B) 40,60,50                                                    ELIP0069
   40 RES=-1.E38                                                        ELIP0070
      RETURN                                                            ELIP0071
   50 RES=1.E38                                                         ELIP0072
      RETURN                                                            ELIP0073
   60 RES=A                                                             ELIP0074
      RETURN                                                            ELIP0075
C                                                                       ELIP0076
C     COMPUTE INTEGRAL                                                  ELIP0077
C                                                                       ELIP0078
   70 ARI=1.                                                            ELIP0079
      AA=A                                                              ELIP0080
      AN=A+B                                                            ELIP0081
      W=B                                                               ELIP0082
   80 W=W+AA*GEO                                                        ELIP0083
      W=W+W                                                             ELIP0084
      AA=AN                                                             ELIP0085
      AARI=ARI                                                          ELIP0086
      ARI=GEO+ARI                                                       ELIP0087
      AN=W/ARI+AN                                                       ELIP0088
C                                                                       ELIP0089
C     TEST OF ACCURACY                                                  ELIP0090
C                                                                       ELIP0091
      IF(AARI-GEO-1.E-4*AARI) 100,100,90                                ELIP0092
   90 GEO=SQRT(GEO*AARI)                                                ELIP0093
      GEO=GEO+GEO                                                       ELIP0094
      GO TO 80                                                          ELIP0095
  100 RES=.78539816*AN/ARI                                              ELIP0096
      RETURN                                                            ELIP0097
      END                                                               ELIP0098
```

```
$IBFTC TRP2    M94,XR7,DECK
      REAL FUNCTION  TRP2(T,X,Y,M)
      DIMENSION T( 1000),Z(4),D(6)
      L1=0
      X1=X
      Y1=Y
      I=T(1)/1000.+1.
      J=AMOD(T(1),1000.)+1.
      L=J*M
      I1=J*3+1
      I2=I*J
      M1=M
      DO 10 K=I1,I2,L
      IF(X1-T(K)) 20,20,10
   10 CONTINUE
      K=I2+1-J
   20 DO 30 L=4,J,M1
      IF (Y1-T(L)) 40,40,30
   30 CONTINUE
      L=J
   40 L1=L1+1
      DO 50 MN=1,3
      N=L+MN-3
      N1=K+(J*(L1-3))+N-1
      D(MN)=T(N)
   50 D(MN+3)=T(N1)
   60 Z(L1)=D(4)+(Y1-D(1))*((D(5)-D(4))/(D(2)-D(1))+(
     1Y1-D(2))/(D(3)-D(1))*((D(6)-D(5))/(D(3)-D(2))
     2-(D(5)-D(4))/(D(2)-D(1))))
      IF (L1-3)40,70,90
   70 DO 80 MN=1,3
      D(MN+3)=Z(MN)
      N1=K+(J*(MN-3))
   80 D(MN)=T(N1)
      L1=4
      Y1=X
      GO TO 60
   90  TRP2=Z(4)
      RETURN
      END
```

```
$IBFTC TIFANY  M94,XR7,DECK                                          TIFA0000
      BLOCK DATA                                                     TIFA0001
      COMMON /MKCURV/ MK(1000)                                       TIFA0002
      REAL MK                                                        TIFA0003
      DATA(MK(I),I=1,84)/                                            TIFA0004
     1    11006.,0.05,0.10,0.20,0.30,0.40,0.50,                      TIFA0005
     2          0.0,1.00,1.00,1.00,1.00,1.00,1.00,                   TIFA0006
     3          0.1,1.01,1.01,1.01,1.01,1.01,1.00,                   TIFA0007
     4          0.2,1.03,1.03,1.02,1.02,1.01,1.00,                   TIFA0008
     5          0.3,1.06,1.06,1.04,1.03,1.02,1.00,                   TIFA0009
     6          0.4,1.12,1.12,1.08,1.05,1.02,1.00,                   TIFA0010
     7          0.5,1.22,1.18,1.14,1.08,1.03,1.00,                   TIFA0011
     8          0.6,1.34,1.30,1.22,1.13,1.06,1.01,                   TIFA0012
     9          0.7,1.48,1.42,1.31,1.20,1.08,1.02,                   TIFA0013
     A          0.8,1.64,1.57,1.41,1.26,1.13,1.04,                   TIFA0014
     B          0.9,1.77,1.68,1.50,1.32,1.18,1.08,                   TIFA0015
     C          1.0,1.84,1.75,1.59,1.38,1.22,1.10/                   TIFA0016
      END                                                            TIFA0017
```

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APPENDIX II

ILLUSTRATIVE PROBLEM

Let's consider a typical mission profile for a tactical aircraft. This mission will consist of: a low level penetration run, a pullup over the target, a military power climb, a roll and pullover, a dive followed by a 5 "g" pullup, a low level dash followed by a 4 "g" pullup into a military power climb and return cruise to a normal landing. The flight description is taken from reference 9 and is given in Table II and loads description in Table III. Assume that during the low level penetration, the aircraft sustains damage which may be modeled as a through crack of length 1.74 inches. The input cards for this problem are given in Table IV and the output is in Table V. If the damage is modeled as a through crack of length 2.103, the input changes are shown in Table VI and the output is in Table VII. Comparisons with analytical results from reference 9 show that both analyses predict the same number of cycles to failure for both cases.

TABLE II

MISSION PROFILE DESCRIPTION

Condition	Description	Airspeed	n_z	Number Gust Cycles	
				$\Delta n_z = 0.26$	$\Delta n_z = 0.42$
1	Low Level Dash	450 kt	1	8	1
2	180° Turn	450 kt	2	8	1
3	Low Level Dash	450 kt	1	8	1
4	180° Turn	450 kt	2	8	1
5	Low Level Dash	450 kt	1	8	1
6	180° Turn	450 kt	2	8	1
7	Low Level Dash	450 kt	1	8	1
8	180° Turn	450 kt	2	8	1
9	Low Level Dash	450 kt	1	8	1
10	180° Turn	450 kt	2	8	1
11	Low Level Dash	450 kt	2	8	1
12	180° Turn	450 kt	2	8	1
13	Low Level Dash	450 kt	2	8	1
14	Pullup	450 kt	4	—	—
15	Military Power Climb	0.87 M	0	—	—
16	Roll and Pullover	0.87 M	3	—	—
17	Dive	0.87 M	0	—	—
18	Pullup	0.87 M	5	—	—
41	Military Power Climb	0.87 M	0	64	8
42	Cruise	0.87 M	1	16	3
43	Descend	0.87 M	0	8	1
44	Low Level Flight	175 kt	1	12	2
45	180° Turn	175 kt	2	12	2
46	Low Level Flight	175 kt	1	12	2
47	180° Turn	175 kt	2	12	2
48	Final Descent	145 kt	0		

TABLE III

LOADS FOR MISSION PROFILE

Cond	Δσ (psi)	R	N (cycles)
1	4850	0	1
1	2000	0.588	7
1	3240	0.408	1
2	6470	0.256	1
2	2000	0.770	7
2	3240	0.652	1
3	2000	0.588	8
3	3240	0.408	1
4	6470	0.256	1
4	2000	0.770	7
4	3240	0.652	1
5	2000	0.588	8
5	3240	0.408	1
6	6470	0.256	1
6	2000	0.770	7
6	3240	0.652	1
7	2000	0.588	8
7	3240	0.408	1
8	6470	0.256	1
8	2000	0.770	7
8	3240	0.652	1
9	2000	0.588	8
9	3240	0.408	1
10	6470	0.256	1
10	2000	0.770	7
10	3240	0.652	1
11	2000	0.588	8
11	3240	0.408	1
12	6470	0.256	1
12	2000	0.770	7
12	3240	0.652	1
13	2000	0.588	8
13	3240	0.408	1
14	13170	0.145	1
15-16	11450	0.009	1
17-18	19150	0.005	1
41	2000	0.194	64
41	3240	0.031	8
42	5370	0.019	3
42	2000	0.588	16
43	2000	0.194	8
43	3240	0.031	1
44	5370	0.019	1
44	2000	0.588	12
44	3240	0.408	1
45	7090	0.240	1
45	2000	0.770	12
45	3240	0.652	1
46	2000	0.588	12
46	3240	0.408	2
47	7090	0.240	1
47	2000	0.770	12
47	3240	0.652	1

TABLE IV

DATA DECK FOR PROBLEM 1

OTFDTRJUL65100

```
         1         2         3         4
1234567890123456789012345678901234567890
TYPICAL FIGHTER-BOMBER MISSION
FORMAN    7075-T6 ALUMINUM
5.13E-13  3.0       39000.
1.940
BETA2.    8.0
BETA0
0.        4
RANGE
1    4850.     0.        1.
1    2000.     0.588     7.
1    3240.     0.408     1.
2    6470.     0.256     1.
2    2000.     0.770     7.
2    3240.     0.652     1.
3    2000.     0.588     8.
3    3240.     0.408     1.
4    6470.     0.256     1.
4    2000.     0.770     7.
4    3240.     0.652     1.
5    2000.     0.588     8.
5    3240.     0.408     1.
6    6470.     0.256     1.
6    2000.     0.770     7.
6    3240.     0.652     1.
7    2000.     0.588     8.
```

TABLE IV (CONTD)

OTFDTRJUL65100

7	3240.	0.408	1.
8	6470.	0.256	1.
8	2000.	0.770	7.
8	3240.	0.652	1.
9	2000.	0.588	8.
9	3240.	0.408	1.
10	6470.	0.256	1.
10	2000.	0.770	7.
10	3240.	0.652	1.
11	2000.	0.588	8.
11	3240.	0.408	1.
12	6470.	0.252	1.
12	2000.	0.770	7.
12	3240.	0.652	1.
13	2000.	0.588	8.
13	3240.	0.408	1.
14	13170.	0.145	1.
15-16	11450.	0.009	1.
17-18	19150.	0.005	1.
41	2000.	0.194	64.
41	3240.	0.031	8.
42	5370.	0.019	3.
42	2000.	0.588	16.
43	2000.	0.194	8.
43	3240.	0.031	1.

TABLE IV (CONTD)

CTFDTRJUL65100

44	5370.	0.019	1.
44	2000.	0.588	12.
44	3240.	0.408	1.
45	7090.	0.240	1.
45	2000.	0.770	12.
45	3240.	0.652	1.
46	2000.	0.588	12.
46	3240.	0.408	2.
47	7090.	0.240	1.
47	2000.	0.770	12.
47	3240.	0.652	1.
END			

TABLE V

```
TYPICAL FIGHTER-BOMBER MISSION

MATERIAL CONSTANTS      7075-T6 ALUMINUM
C =  0.51300000E-12     SMALLN = 3.00     KSUBC =  0.38999999E 05     YIELD STRESS = -0.

INITIAL HALF CRACK LENGTH =  C.17399999E 01

CORRECTION FACTORS USED FOR DELTA K

DELTA K =(DELTA T)*SQRT(PI*A)*BETA(1)*BETA(2)*...BETA(I)

BETA(2)-FINITE WIDTH CORRECTION FACTOR
        BETA(2) = SQRT(2/(PI*A/B)*TAN(PI*(A/B)/2))
        WHERE....B =  0.80000000E 01

INITIAL CYCLE NUMBER =      0.

REPEAT INPUT SPECTRUM    4 TIMES
```

TABLE V (CONTD)

	LOAD BLOCK	NUMBER OF CYCLES PER LOAD BLOCK	NUMBER OF CYCLE AT END OF BLOCK	DELTA SIGMA	R	INTEGRATION INTERVAL (CYCLES)
1	1	1.000	1.000	4850.00	0.	1.000
1	2	7.000	8.000	2000.00	0.588	7.000
1	3	1.000	9.000	3240.00	0.408	1.000
2	4	1.000	10.000	6470.00	0.256	1.000
2	5	7.000	17.000	2000.00	0.770	7.000
2	6	1.000	18.000	3240.00	0.652	1.000
3	7	8.000	26.000	2000.00	0.588	8.000
3	8	1.000	27.000	3240.00	0.408	1.000
4	9	1.000	28.000	6470.00	0.256	1.000
4	10	7.000	35.000	2000.00	0.770	7.000
4	11	1.000	36.000	3240.00	0.652	1.000
5	12	8.000	44.000	2000.00	0.588	8.000
5	13	1.000	45.000	3240.00	0.408	1.000
6	14	1.000	46.000	6470.00	0.256	1.000
6	15	7.000	53.000	2000.00	0.770	7.000
6	16	1.000	54.000	3240.00	0.652	1.000
7	17	8.000	62.000	2000.00	0.588	8.000
7	18	1.000	63.000	3240.00	0.408	1.000
8	19	1.000	64.000	6470.00	0.256	1.000
8	20	7.000	71.000	2000.00	0.770	7.000
8	21	1.000	72.000	3240.00	0.652	1.000
9	22	8.000	80.000	2000.00	0.588	8.000
9	23	1.000	81.000	3240.00	0.408	1.000
10	24	1.000	82.000	6470.00	0.256	1.000
10	25	7.000	89.000	2000.00	0.770	7.000
10	26	1.000	90.000	3240.00	0.652	1.000
11	27	8.000	98.000	2000.00	0.588	8.000
11	28	1.000	99.000	3240.00	0.408	1.000
12	29	1.000	100.000	6470.00	0.256	1.000
12	30	7.000	107.000	2000.00	0.770	7.000
12	31	1.000	108.000	3240.00	0.652	1.000
13	32	8.000	116.000	2000.00	0.588	8.000
13	33	1.000	117.000	3240.00	0.408	1.000
14	34	1.000	118.000	13170.00	0.145	1.000
15-16	35	1.000	119.000	11450.00	0.009	1.000
17-18	36	1.000	120.000	19150.00	0.035	1.000
41	37	64.000	184.000	2000.00	0.194	64.000
41	38	8.000	192.000	3240.00	0.031	8.000
42	39	3.000	195.000	5370.00	0.019	3.000
42	40	16.000	211.000	2000.00	0.588	16.000
43	41	8.000	219.000	2000.00	0.194	8.000
43	42	1.000	220.000	3240.00	0.031	1.000
44	43	1.000	221.000	5370.00	0.019	1.000
44	44	12.000	233.000	2000.00	0.588	12.000
44	45	1.000	234.000	3240.00	0.408	1.000
45	46	1.000	235.000	7090.00	0.240	1.000
45	47	12.000	247.000	2000.00	0.770	12.000
45	48	1.000	248.000	3240.00	0.652	1.000
46	49	12.000	260.000	2000.00	0.588	12.000
46	50	2.000	262.000	3240.00	0.408	2.000
47	51	1.000	263.000	7090.00	0.240	1.000
47	52	12.000	275.000	2000.00	0.770	12.000
47	53	1.000	276.000	3240.00	0.652	1.000

TABLE V (CONTD)

	LOAD BLOCK	NUMBER OF CYCLES PER LOAD BLOCK	NUMBER OF CYCLE AT END OF BLOCK	DELTA SIGMA	R	INTEGRATION INTERVAL (CYCLES)
1	1	1.000	1.000	4850.00	0.	1.000
1	2	7.000	8.000	2000.00	0.588	7.000
1	3	1.000	9.000	3240.00	0.408	1.000
2	4	1.000	10.000	6470.00	0.256	1.000
2	5	7.000	17.000	2000.00	0.770	7.000
2	6	1.000	18.000	3240.00	0.652	1.000
3	7	8.000	26.000	2000.00	0.588	8.000
3	8	1.000	27.000	3240.00	0.408	1.000
4	9	1.000	28.000	6470.00	0.256	1.000
4	10	7.000	35.000	2000.00	0.770	7.000
4	11	1.000	36.000	3240.00	0.652	1.000
5	12	8.000	44.000	2000.00	0.588	8.000
5	13	1.000	45.000	3240.00	0.408	1.000
6	14	1.000	46.000	6470.00	0.256	1.000
6	15	7.000	53.000	2000.00	0.770	7.000
6	16	1.000	54.000	3240.00	0.652	1.000
7	17	8.000	62.000	2000.00	0.588	8.000
7	18	1.000	63.000	3240.00	0.408	1.000
8	19	1.000	64.000	6470.00	0.256	1.000
8	20	7.000	71.000	2000.00	0.770	7.000
8	21	1.000	72.000	3240.00	0.652	1.000
9	22	8.000	80.000	2000.00	0.588	8.000
9	23	1.000	81.000	3240.00	0.408	1.000
10	24	1.000	82.000	6470.00	0.256	1.000
10	25	7.000	89.000	2000.00	0.770	7.000
10	26	1.000	90.000	3240.00	0.652	1.000
11	27	8.000	98.000	2000.00	0.588	8.000
11	28	1.000	99.000	3240.00	0.408	1.000
12	29	1.000	100.000	6470.00	0.256	1.000
12	30	7.000	107.000	2000.00	0.770	7.000
12	31	1.000	108.000	3240.00	0.652	1.000
13	32	8.000	116.000	2000.00	0.588	8.000
13	33	1.000	117.000	3240.00	0.408	1.000
14	34	1.000	118.000	13170.00	0.145	1.000
15-16	35	1.000	119.000	11450.00	0.009	1.000
17-18	36	1.000	120.000	19150.00	0.035	1.000
41	37	64.000	184.000	2000.00	0.194	64.000
41	38	8.000	192.000	3240.00	0.031	8.000
42	39	3.000	195.000	5370.00	0.019	3.000
42	40	16.000	211.000	2000.00	0.588	16.000
43	41	8.000	219.000	2000.00	0.194	8.000
43	42	1.000	220.000	3240.00	0.031	1.000
44	43	1.000	221.000	5370.00	0.019	1.000
44	44	12.000	233.000	2000.00	0.588	12.000
44	45	1.000	234.000	3240.00	0.408	1.000
45	46	1.000	235.000	7090.00	0.240	1.000
45	47	12.000	247.000	2000.00	0.770	12.000
45	48	1.000	248.000	3240.00	0.652	1.000
46	49	12.000	260.000	2000.00	0.588	12.000
46	50	2.000	262.000	3240.00	0.408	2.000
47	51	1.000	263.000	7090.00	0.240	1.000
47	52	12.000	275.000	2000.00	0.770	12.000
47	53	1.000	276.000	3240.00	0.652	1.000

TABLE VI

DATA DECK FOR PROBLEM 2

Cols 1–5	Cols 6–10	Cols 11–15	Cols 16–20	Cols 21–25	Cols 26–30
TYPICAL FIGHTER-BOMBER MISSION					
FORMAN		7075-T6 ALUMINUM			
5.13E-13		3.0		39000.	
2.103					
BETA2		8.0			
BETAO					
0.		4			
RANGE					
1	4850.		0.		1.
1	2000.		0.588		7.
1	3240.		0.408		1.
2	6470.		0.256		1.
2	2000.		0.770		7.
2	3240.		0.652		1.
3	2000.		0.588		8.
3	3240.		0.408		1.
4	6470.		0.256		1.
4	2000.		0.770		7.
4	3240.		0.652		1.
5	2000.		0.588		8.
5	3240.		0.408		1.
6	6470.		0.256		1.
6	2000.		0.770		7.
6	3240.		0.652		1.
7	2000.		0.588		8.

TABLE VI (CONTD)

OTFDTRJUL65100

7	3240.	0.408	1.
8	6470.	0.256	1.
8	2000.	0.770	7.
8	3240.	0.652	1.
9	2000.	0.588	8.
9	3240.	0.408	1.
10	6470.	0.256	1.
10	2000.	0.770	7.
10	3240.	0.652	1.
11	2000.	0.588	8.
11	3240.	0.408	1.
12	6470.	0.256	1.
12	2000.	0.770	7.
12	3240.	0.652	1.
13	2000.	0.588	8.
13	3240.	0.408	1.
14	13170.	0.145	1.
15-16	11450.	0.009	1.
17-18	19150.	0.005	1.
41	2000.	0.194	64.
41	3240.	0.031	8.
42	5370.	0.019	3.
42	2000.	0.588	16.
43	2000.	0.194	8.
43	3240.	0.031	1.

TABLE VI (CONTD)

OTFDTRJUL65100

44	5370.	0.019	1.
44	2000.	0.588	12.
44	3240.	0.408	1.
45	7090.	0.240	1.
45	2000.	0.770	12.
45	3240.	0.652	1.
46	2000.	0.588	12.
46	3240.	0.408	2.
47	7090.	0.240	1.
47	2000.	0.770	12.
47	3240.	0.652	1.
END			

TABLE VII

```
TYPICAL FIGHTER-BOMBER MISSION

MATERIAL CONSTANTS       7075-T6 ALUMINUM
C =  0.51300000E-12      SMALLN = 3.00      KSUBC =  0.38999999E 05      YIELD STRESS = -0.

INITIAL HALF CRACK LENGTH =  0.21029999E 01

CORRECTION FACTORS USED FOR DELTA K

DELTA K =(DELTA T)*SQRT(PI*A)*BETA(1)*BETA(2)*...BETA(I)

BETA(2)-FINITE WIDTH CORRECTION FACTOR
        BETA(2) = SQRT(2/(PI*A/B)*TAN(PI*(A/B)/2))
        WHERE....B =  0.80000000E 01

INITIAL CYCLE NUMBER =       0.

REPEAT INPUT SPECTRUM    4 TIMES
```

TABLE VII (CONTD)

	LOAD BLOCK	NUMBER OF CYCLES PER LOAD BLOCK	NUMBER OF CYCLE AT END OF BLOCK	DELTA SIGMA	R	INTEGRATION INTERVAL (CYCLES)
1	1	1.000	1.000	4850.00	0.	1.000
1	2	7.000	8.000	2000.00	0.588	7.000
1	3	1.000	9.000	3240.00	0.408	1.000
2	4	1.000	10.000	6470.00	0.256	1.000
2	5	7.000	17.000	2000.00	0.770	7.000
2	6	1.000	18.000	3240.00	0.652	1.000
3	7	8.000	26.000	2000.00	0.588	8.000
3	8	1.000	27.000	3240.00	0.408	1.000
4	9	1.000	28.000	6470.00	0.256	1.000
4	10	7.000	35.000	2000.00	0.770	7.000
4	11	1.000	36.000	3240.00	0.652	1.000
5	12	8.000	44.000	2000.00	0.588	8.000
5	13	1.000	45.000	3240.00	0.408	1.000
6	14	1.000	46.000	6470.00	0.256	1.000
6	15	7.000	53.000	2000.00	0.770	7.000
6	16	1.000	54.000	3240.00	0.652	1.000
7	17	8.000	62.000	2000.00	0.588	8.000
7	18	1.000	63.000	3240.00	0.408	1.000
8	19	1.000	64.000	6470.00	0.256	1.000
8	20	7.000	71.000	2000.00	0.770	7.000
8	21	1.000	72.000	3240.00	0.652	1.000
9	22	8.000	80.000	2000.00	0.588	8.000
9	23	1.000	81.000	3240.00	0.408	1.000
10	24	1.000	82.000	6470.00	0.256	1.000
10	25	7.000	89.000	2000.00	0.770	7.000
10	26	1.000	90.000	3240.00	0.652	1.000
11	27	8.000	98.000	2000.00	0.588	8.000
11	28	1.000	99.000	3240.00	0.408	1.000
12	29	1.000	100.000	6470.00	0.256	1.000
12	30	7.000	107.000	2000.00	0.770	7.000
12	31	1.000	108.000	3240.00	0.652	1.000
13	32	8.000	116.000	2000.00	0.588	8.000
13	33	1.000	117.000	3240.00	0.408	1.000
14	34	1.000	118.000	13170.00	0.145	1.000
15-16	35	1.000	119.000	11450.00	0.009	1.000
17-18	36	1.000	120.000	19150.00	0.035	1.000
41	37	64.000	184.000	2000.00	0.194	64.000
41	38	8.000	192.000	3240.00	0.031	8.000
42	39	3.000	195.000	5370.00	0.019	3.000
42	40	16.000	211.000	2000.00	0.588	16.000
43	41	8.000	219.000	2000.00	0.194	8.000
43	42	1.000	220.000	3240.00	0.031	1.000
44	43	1.000	221.000	5370.00	0.019	1.000
44	44	12.000	233.000	2000.00	0.588	12.000
44	45	1.000	234.000	3240.00	0.408	1.000
45	46	1.000	235.000	7090.00	0.240	1.000
45	47	12.000	247.000	2000.00	0.770	12.000
45	48	1.000	248.000	3240.00	0.652	1.000
46	49	12.000	260.000	2000.00	0.588	12.000
46	50	2.000	262.000	3240.00	0.408	2.000
47	51	1.000	263.000	7090.00	0.240	1.000
47	52	12.000	275.000	2000.00	0.770	12.000
47	53	1.000	276.000	3240.00	0.652	1.000

TABLE VII (CONTD)

CRACK LENGTH AT BEGINNING OF FLIGHT 1 IS 2.10300

CRACK PROPAGATION ANALYSIS USING FORMAN'S EQUATION
DA/DN=C*(DELTA K)**N/((1-R)*KSUBC-DELTA K)

CYCLE	A	DA/DN	DELTA K	K MAX	MSUBK	Q
1.000	2.10304	0.41523291E-04	12840.99	12840.99	1.000	0.
8.000	2.10309	0.70708467E-05	5295.32	12852.73	1.000	0.
9.000	2.10311	0.22320025E-04	8578.48	14490.67	1.000	0.
10.000	2.10333	0.21702959E-03	17131.47	23026.17	1.000	0.
17.000	2.10348	0.20738335E-04	5295.87	23025.51	1.000	0.
18.000	2.10354	0.64889476E-04	8579.45	24653.60	1.000	0.
26.000	2.10360	0.70741812E-05	5296.04	12854.46	1.000	0.
27.000	2.10362	0.22330852E-04	8579.64	14492.63	1.000	0.
28.000	2.10384	0.21715993E-03	17133.78	23029.28	1.000	0.
35.000	2.10398	0.20750789E-04	5296.58	23028.62	1.000	0.
36.000	2.10405	0.64930879E-04	8580.61	24656.94	1.000	0.
44.000	2.10410	0.70775209E-05	5296.76	12856.20	1.000	0.
45.000	2.10413	0.22341695E-04	8580.79	14494.59	1.000	0.
46.000	2.10434	0.21729036E-03	17136.10	23032.39	1.000	0.
53.000	2.10449	0.20763253E-04	5297.30	23031.74	1.000	0.
54.000	2.10455	0.64972316E-04	8581.77	24660.27	1.000	0.
62.000	2.10461	0.70808626E-05	5297.47	12857.94	1.000	0.
63.000	2.10463	0.22352545E-04	8581.95	14496.55	1.000	0.
64.000	2.10485	0.21742092E-03	17138.42	23035.51	1.000	0.
71.000	2.10499	0.20775728E-04	5298.02	23034.85	1.000	0.
72.000	2.10506	0.65013792E-04	8582.93	24663.60	1.000	0.
80.000	2.10512	0.70842062E-05	5298.19	12859.68	1.000	0.
81.000	2.10514	0.22363402E-04	8583.12	14498.51	1.000	0.
82.000	2.10536	0.21755163E-03	17140.73	23038.62	1.000	0.
89.000	2.10550	0.20788224E-04	5298.73	23037.97	1.000	0.
90.000	2.10557	0.65055323E-04	8584.10	24666.94	1.000	0.
98.000	2.10562	0.70875566E-05	5298.90	12861.42	1.000	0.
99.000	2.10565	0.22374275E-04	8584.28	14500.47	1.000	0.
100.000	2.10586	0.21768250E-03	17143.05	23041.74	1.000	0.
107.000	2.10601	0.20800725E-04	5299.45	23041.09	1.000	0.
108.000	2.10607	0.65096924E-04	8585.26	24670.28	1.000	0.
116.000	2.10613	0.70909073E-05	5299.62	12863.16	1.000	0.
117.000	2.10615	0.22385161E-04	8585.44	14502.43	1.000	0.

((1-R)KSUBC-DELTAK) WENT NEGATIVE AT 117.000 CYCLES

BEGIN SEARCH FOR MORE ACCURATE VALUES
STARTING VALUES

117.000	2.10615	0.22385161E-04	8585.44	14502.43	1.000	0.

******VALUES AT ONSET OF INSTABILITY*****

117.000	2.10615	0.22385161E-04	8585.44	14502.43	1.000	0.

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13. ABSTRACT

This report presents a detailed description of a computer program for analyzing crack propagation in cyclic loaded structures. The program has the option of using relationships derived by Forman or by Paris for crack growth. Provisions are made for both surface flaws and "through cracks" as well as the transition from the former to the latter. The program utilizes a block loading concept wherein the load is applied for a given number of cycles rather than applied from one cycle number to another cycle number. Additional features of the program are: variable print interval, variable integration interval, and optional formats for loads input. Detailed input instructions and an illustrative problem are presented.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Crack Propagation						
2. Variable Amplitude Loading						
3. Digital Computer Methods						

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